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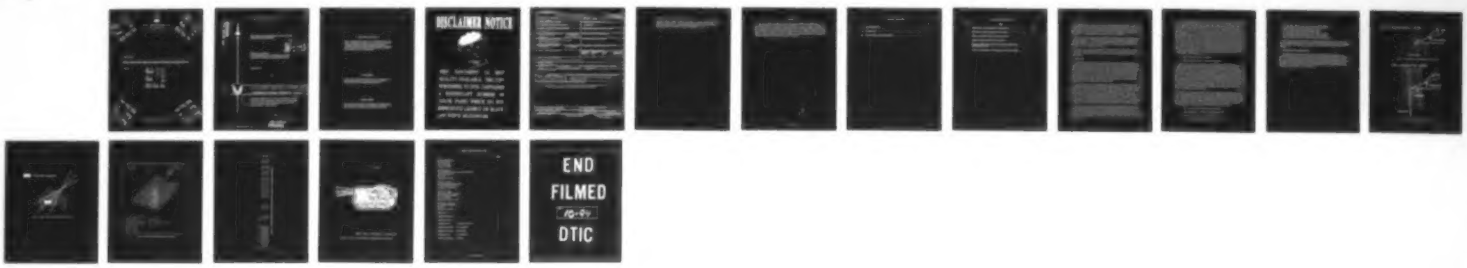

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METHODOLOGY EMPLOYED TO CALCULATE JAVELIN EFFECTIVENESS

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Systems Simulation and Development Directorate
Research, Development, and Engineering Center

August 1994

U. S. ARMY MISSILE COMMAND

Redstone Arsenal, Alabama 35898-5000

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This report provides an overview of the calculations that will be utilized to predict Javelin effectiveness. Topics covered will include Probability of Kill (Pk) and Probability of Hit (Ph).

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FORWARD

This report presents a summary of the technical accomplishments performed by the Systems Simulation and Development Directorate (SS&DD) of U. S. Army Missile Command (MICOM), Research, Development, and Engineering Center (RDEC), Redstone Arsenal, Alabama, supporting the Javelin Program Management Office. Ms. Kimberly Cornelius (SS&DD) was the technical coordinator of this effort. Nichols Research Corporation and the University of Alabama – Huntsville Research Institute (UAHRI) Visualization and Simulation Laboratory provided both engineering and computer support for this effort.

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I. BACKGROUND

The effectiveness calculations for Javelin have evolved greatly in the past two years. The Systems Simulation and Development Directorate (SS&DD) has been tasked to calculate Probability of Kill (Pk) based on output from digital and real–time flight simulations. The U. S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, MD is producing the lethality data for these analyses. The results and data that are produced by the simulations at SS&DD will be forwarded to the U. S. Army Material Systems Analysis Activity (AMSAA).

Software has been developed within SS&DD to manipulate official Pk cell data generated at ARL and to calculate a Pk for Monte Carlo sets of terminal conditions from digital and real–time flight simulations. The software also allows an analysis of these sets through the use of graphical and database techniques. All software was developed on Silicon Graphics computers and written in the "C" computer language.

Meetings were held between the SS&DD, the Javelin Project Office, ARL, and AMSAA to determine how to best fulfill each agency's requirements while representing the system in a proper manner. This report will discuss the lethality effectiveness computations methodology and distribution.

II. ANALYSIS

The SS&DD effort to determine system effectiveness initially consisted of an analysis of the terminal conditions from the digital Six–Degrees–of–Freedom (6–DOF) simulation and the lethality cell maps developed by ARL. These lethality data were provided for certain missile body angles (body angle theta). Each theta consists of a particular trajectory angle (gamma) and an inertial angle of attack (alpha) combination. Figure 1 schematically depicts these angles. The same variations were noted in the yaw plane (Fig. 2). Numerous flight simulation runs have shown that the angles may vary as much as 5 to 10 degrees from run to run. This implies that a mean shotline may not correctly represent the best (or most correct) shotline and improper credit would be attributed to the system. Figure 3 shows a representation of what would happen when varying angles of attack are applied at the terminal point.

Through analyses, it was determined that the existing data did not adequately represent the missile terminal state vector, with its variances of angular orientation. These angular definitions are important for the calculation of lethality maps, since threat vehicles can exhibit large discontinuities from one cell to an adjacent cell. This is highly dependent on the location of critical components and whether the warhead penetrated (or hit) that component. Varying a few centimeters in component location or degrees in shotline orientation can make a large difference in the Pk of a cell. It should be noted that the initial data request was developed by the Javelin prime contractor to obtain design points. These data were not meant for use in a system performance assessment. For this reason SS&DD requested a high resolution, angular oriented Pk data set. This data covers a two sigma variation of the terminal angles, in five degree increments.

To calculate Pk for the Integrated Flight Simulation (IFS) and Hardware–in–the–Loop (HWIL), terminal conditions are received from the digital IFS and HWIL Simulation. Data received from these simulations include a three–dimensional hit point (where 0, 0, 0 is the center of the turret on the ground plane), target azimuth, the trajectory angle in the pitch plane (γp), trajectory angle in the yaw plane (γy), inertial angle of attack (α), and yaw (β). The conditions of the scenario run (countermeasures, background, time of day, season, etc.) are also inputs into the evaluation tools.

The three–dimensional hit point is projected into a two–dimensional (h,v) hit point in the plane normal to the mean trajectory or velocity vector (γp, γy). The dispersions (σh, σv) are calculated in this plane. If the data shows a dependency on season/time (as with short ranges, or non–specification cases) separate dispersions are calculated for each season/time within a Monte Carlo set. The Pk for each run of the Monte Carlo set uses an average Pk from the nine cells (three by three) closest to each (h, v) hit point location on the cell map selected from the nearest terminal angles (γp, γy, α, β). This will be the Pk for that specific run. These Pk values are averaged together to determine the Pk for the Monte Carlo set. This method is known as the Local Pk Method. Probability of hit (Ph) is calculated by dividing the number of hits by the sum of the hits and misses. Some misses are statistical outliers that indicate some form of system failure, such as a loss of lock on the track gates. Since these outliers are system errors and not accuracy errors, logic to exclude them from the (h, v) standard deviation calculation has been incorporated. Outliers are defined as those shots impacting outside of an eight meter radius from the origin of the tank coordinate system. Two types of Pk are defined, the Pk given a shot (Pks) and the Pk given an engagement (Pke). Pke includes the effects of the system rejecting an initial lock of the target, note that this is a different definition than that defined in the Javelin Specifications Document. The definitions are:

Pks = ΣPk for each hit/ (# hits + # misses)

Pke = ΣPk for each hit/ (# hits + # misses and rejections).

Output from the analysis of each Monte Carlo set included the identification of mean terminal angles, Center of Presented Area (CPA), mean hit point, the number of hits, misses, rejections, aborts, and outliers, Ph, and Pks and Pke for mobility, firepower, mobility/firepower, and catastrophic kills. Since an abort is a simulation failure and has no relation to the performance of the system, those runs are excluded from any calculations. There are three encoded words that show the conditions incorporated into the Monte Carlo set (background, location, counter–measure, etc.). A grid of the target will be provided displaying the dispersions, CPA, Center of Hitpoint Dispersion, and hit points identified by the four different season/time variables. Figure 4 shows a sample output of the Monte Carlo analysis. Several types of files were created for further analyses, each were utilized to investigate the cardioid or Combat Vehicle Combat Performance Operations Assessment (CV–CPOA) weighting. These files are created for use at other agencies. One such file is the SUMLIN file, a sample is shown in Figure 5. It will include all runs for a particular target or topical study.

Since there is such a large amount of cell–by–cell data for each target, there is some difficulty in other agencies utilizing the data. For example, AMSAA required a single cell map file for each range and azimuth, to perform their analyses. SS&DD created a single file by taking the cell map files for a specific target, and applying a normal distribution of the terminal angles (γp, γy, α, β) about each cell on a plane normal to the mean velocity vector at that range. The normal distribution is based on the 6–DOF runs completed by the Joint Venture to characterize the systems behavior. The equation for the formulation of these cell maps is

$$Pk = \Sigma_{\gamma p}\, \Sigma_{\alpha}\, \Sigma_{\gamma y}\, \Sigma_{\beta}\, Poccurrence_{\gamma p \alpha \gamma y \beta}\, Pk_{\gamma p \alpha \gamma y \beta}$$

$$Poccurrence_{\gamma p \alpha \gamma y \beta} = (fne(\gamma p2/1.414) - fne(\gamma p1/1.414))^{*}$$

$$(fne(\alpha 2/1.414) - fne(\alpha 1/1.414)\ (fne(\gamma y2/1.414) -$$

$$fne(\gamma y1/1.414))\ {*}\ (fne(\beta 2/1.414) - fne(\beta 1/1.414))/16.0$$

where

$\gamma p2$ is the upper bound of the velocity vector in the pitch plane
$\gamma p1$ is the lower bound of the velocity vector in the pitch plane
$\alpha 2$ is the upper bound of the inertial angle of attack
$\alpha 1$ is the lower bound of the inertial angle of attack
$\gamma y2$ is the upper bound of the velocity vector in the yaw plane
$\gamma y1$ is the lower bound of the velocity vector in the yaw plane
FNE is a standard error function found in most statistical manuals.

Figure 6 shows an example of the a cell–by–cell map created by this means. Note the excess cells on the edges of the target, these contribute very little Pk and may be ignored when applying an analyses to the CPA. These cells are caused by the variations in the occurrence of the terminal angles.

III. CONCLUSIONS AND RESULTS

The SS&DD will provide data for the overall Javelin Performance Assessment. Any topical studies needed for system evaluation were also evaluated with this effectiveness methodology. Pk and accuracy data will be provided from the IFS and HWIL simulations. Cell–by–cell data for specific ranges that are independent of the natural angular variations will be created and supplied to various government and contractor organizations. This methodology will be employed for all targets run in the Javelin Performance Assessment. Results of the Performance Assessment will be published in a separate report.

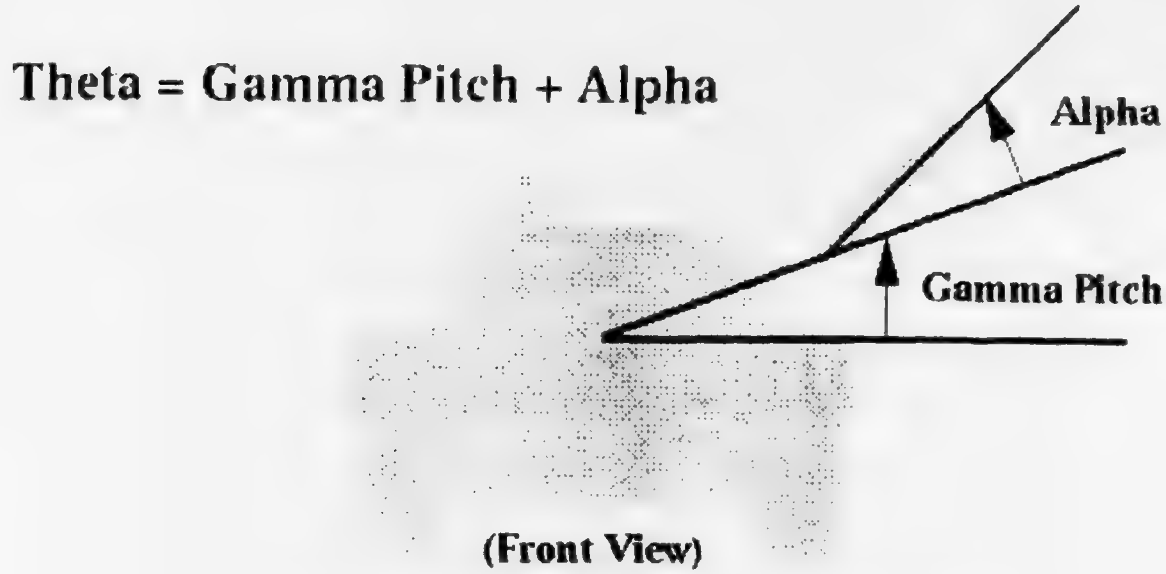

Figure 1. Missile Body Angle Definitions for Pitch Plane

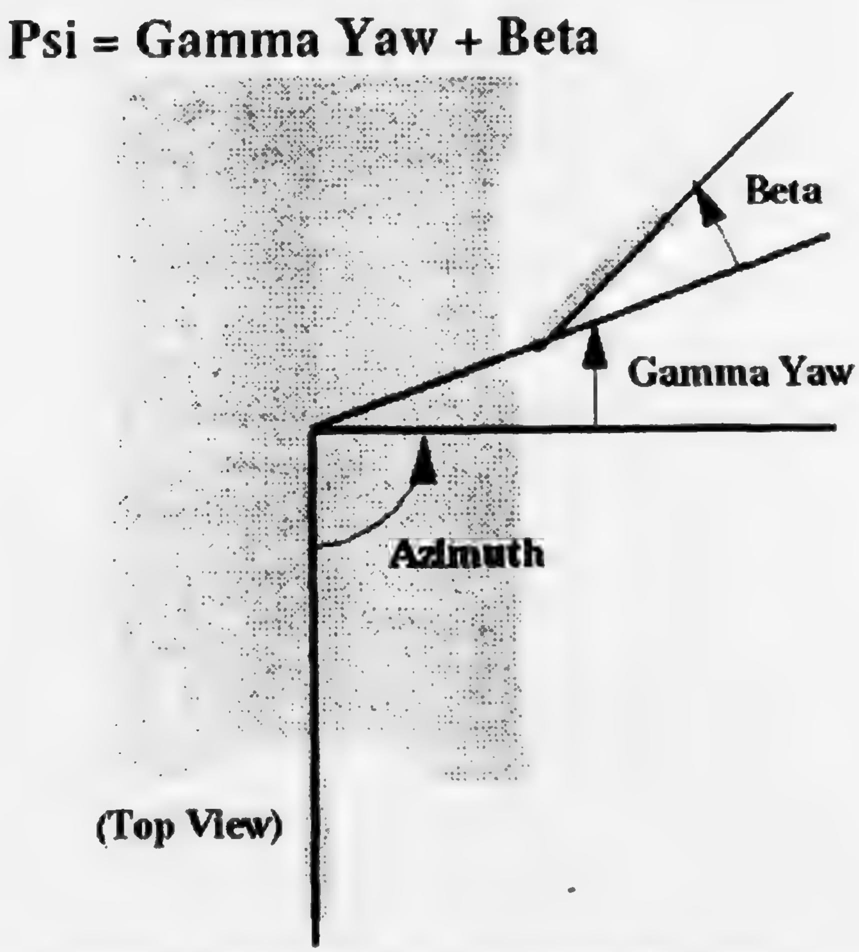

Figure 2. Missile Body Angle Definitions for Yaw Plane

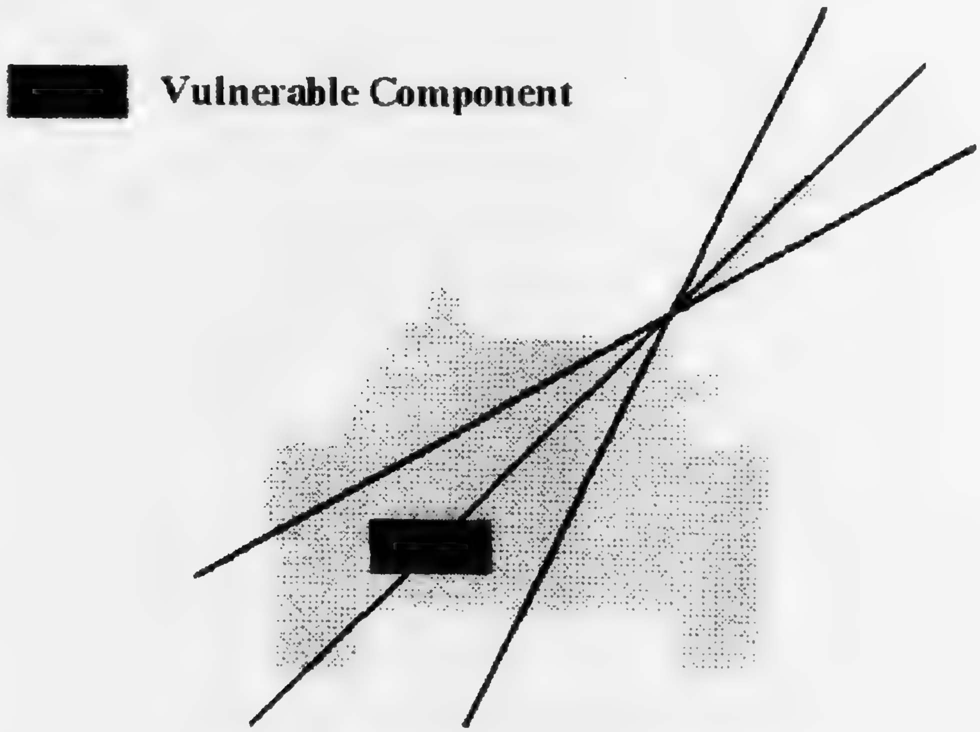

Figure 3. Effects of Varying Trajectory/Angle of Attack

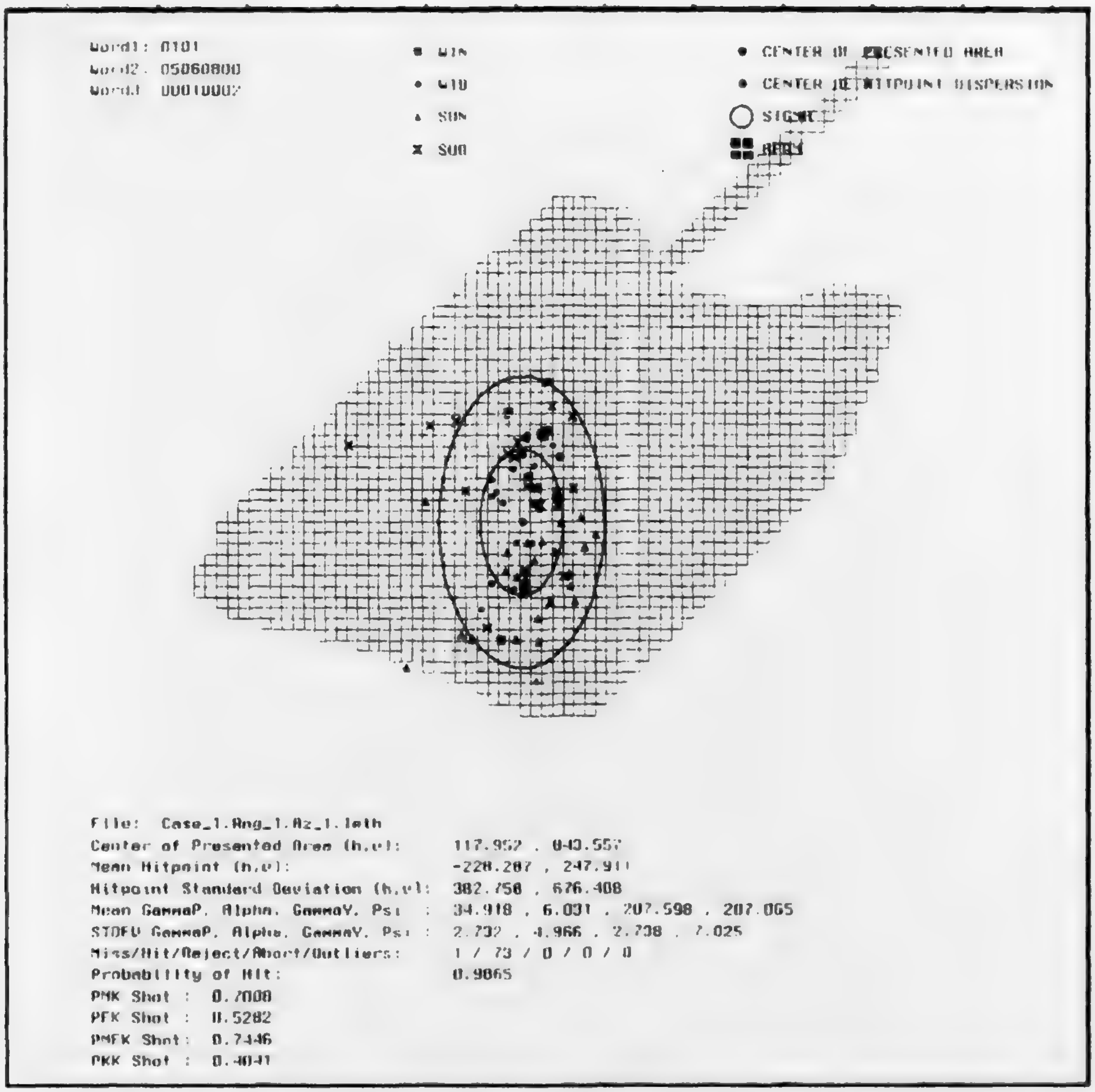

Figure 4. Sample Output for Monte Carlo Analysis

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ALL 01010001000205000608      -228.3      247.9        118.0 843.6 382.8 676.4 .7008 .5282 .7446 .4041
SUD 01010001000205000608      -394.7      687.7        118.0 843.6 581.2 582.3 .7131 .6851 .7630 .5655
SUN 01010001000205000608      -153.9      -261.6       118.0 843.6 403.1 451.9 .6632 .3129 .6856 .2162
WID 01010001000205000608      -279.6      464.5        118.0 843.6 180.2 531.6 .7709 .6681 .8254 .5244
WIN 01010001000205000608      -115.9      727.7        118.0 843.6 163.8 663.7 .6564 .6748 .7344 .5011
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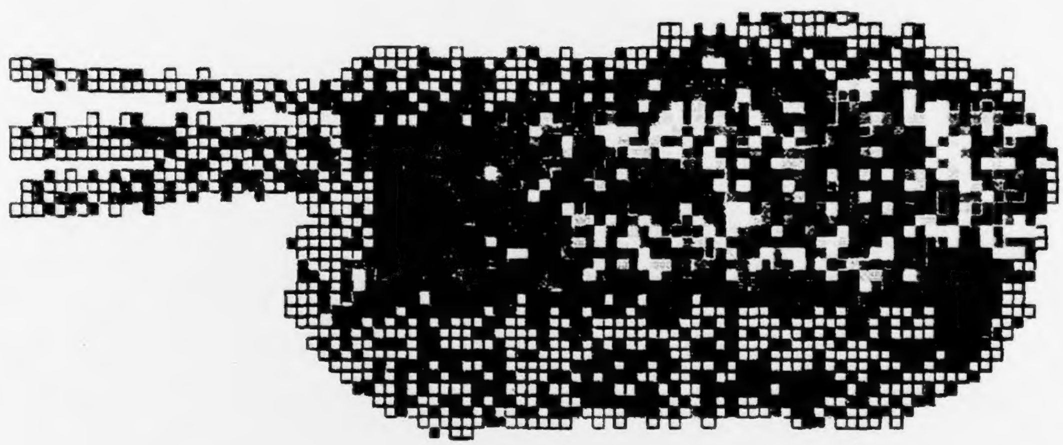
Figure 5. Sample SUMLIN File Utilized to Summarize Monte Carlo Statistics and Results

Sample



Kill Type: Mobility / Firepower

Figure 6. Cell–by–Cell Map Based on Weighting of Terminal Angles

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